REMARKS

This Amendment is a response to a second, non-final Office Action mailed on December 22, 2003. Claims 7-8 are amended as described. Claim 13 was previously cancelled without prejudice or disclaimer. Claims 1-12 and 14-18 remain in the case.

The Office Action rejected Claims 7-12 and 14 under 35 U.S.C. 102(b) as being anticipated by *Otsuka* (U.S. Patent No. 5,493,395). Applicant respectfully traverses this rejection in its entirety.

The present invention, as described in specific claims, is drawn to a distance measuring device implemented with a non-standard heterodyne interferometer system including carrier phase modulation that increases the accuracy in distance measurement by <u>minimizing self-interference</u> (Specification page 2 ll. 16-20). The phase modulation frequency and magnitude are chosen appropriately for the measured distance (Specification page 3 ll. 12-13). The measured distance L spans a distance between two reflectors, a target reflector and a reference reflector (Fig. 1 and Specification page 5 ll. 11-23). A target beam traveling to and between the reflectors experiences a differential delay and generates an intensity modulation that is used to discriminate and isolate a target signal from a parasitic self-interference beat resulting from leakage and scatter (Specification page 7 ll. 9-13). The self-interference which results from the local and reference beams traveling nearly identical path lengths does not pick up intensity modulation at the modulation frequency (Specification page 3 ll. 9-11). The target beam and the reference beam can be frequency shifted by frequency shifters to generate a heterodyne frequency f where the heterodyne frequency f depends on the difference in frequency between

the target beam and the reference beam, shown as $f = f_2 - f_1$ when both the target leg and the reference leg are frequency shifted by a different frequency (Specification page 4 ll. 12-14). Alternatively, either the target leg or the reference leg may be frequency shifted. In another alternative, neither the target leg nor the reference leg is frequency shifted, and the detection relies solely on detecting the pure phase modulation converted into intensity modulation (Specification page 3 ll. 2-4).

In contrast, Otsuka is drawn to a wavelength measuring apparatus that uses a standard heterodyne interferometer. Otsuka does not disclose a phase modulator element as used in the present invention. Otsuka discloses elements 14a and 14b which are termed "AO (acousto-optical) modulators", but these items are not phase modulators and are instead clearly described as frequency shifters (Otsuka col. 3 ll. 8-14). The phase modulator of the present invention applies a phase modulation to the carrier frequency before applying the modulated carrier to one or more frequency shifters to generate the heterodyne signal (Specification page page 2 ll. 18-20 and page 4 ll. 9-12). In Otsuka, the light in the target path is passed through a predetermined optical path via two prism reflecting mirrors as an optical path length difference imparting means in order to provide greater detection of the wavelength variation (Otsuka col. 3 ll. 14-19). The larger the length difference, the greater the ability to measure wavelength variations with a relatively unstable laser light source. On the other hand, if the laser light source was stable, the apparatus of Otsuka could then be used to measure an optical path length difference. Otsuka discloses measuring an amount of <u>movement</u> of a separate reference mirror, which is different from the two prism reflecting mirrors used to measure the wavelength variation (Otsuka col. 4 ll. 29-31). The measurement of a change in distance, caused by movement relative to some initial

position, is a common application of a standard interferometer without carrier phase modulation. Fundamentally, Otsuka does not disclose the improvement of isolating the target signal and excluding the self-interference signal as claimed in the present invention.

Independent Claim 7 is amended to include the phase modulation of Claim 8. Applicant respectfully submits that Otsuka does not teach or imply phase modulation of the carrier signal, and cannot therefore anticipate Claim 7 as amended. Applicant respectfully submits the attached web-page article entitled "Introduction to AO Modulators" by *NeosTech* as a teaching regarding Acousto-Optic (AO) Modulators:

http://www.neostech.com/neos/catalog/introaom.htm

The AO Modulator, as taught in Otsuka, is a device that angularly deflects and shifts the frequency of an incident light beam. An AO Modulator (AOM) includes an underlying device called a Bragg Cell. The names "Bragg Cell" and "AOM" are sometimes used interchangeably. An AO Modulator can be used to modulate the intensity of light and/or shift the frequency of light. Applicant respectfully submits that both the present disclosure and the Otsuka reference use AO Modulators as frequency shifters only. The article teaches:

1) the use of amplitude modulation (AM) as the form of modulation, not phase modulation (PM) (*NeosTech* page 1 ll. 15-16); and

2) the beam is shifted by an amount equal to the acoustic frequency (*NeosTech* page 1 ll. 16-17 and page 3 ll. 8-9).

Applicant respectfully submits that the phase information discussed in *NeosTech* is a static value if the distance is not changing, and that the phase information is not the same as phase modulation (*NeosTech* page 1 ll. 18-19).

Claim 8 depends from Claim 7 and is amended to remove the material incorporated from Claim 8 into Claim 7. Claims 8, as amended, still recites the first portion of the phase modulated carrier signal is demodulated at the modulation frequency. This element is not taught or implied in Otsuka. Applicant respectfully submits that the "phase difference" caused by the optical path length difference in the traditional interferometer taught by Otsuka gives rise to a static phase relationship between the optical two paths and is not a phase modulation (Otsuka col. 3 ll. 13-18 and 42-45). In Otsuka, the phase output Φ1 is a measure of the difference between the first beat signal obtained by the photodetector with the third beat signal obtained by the RF mixer (Otsuka col. 4 ll. 44-57). Otsuka teaches that the phase output Φ1 can fluctuate, but this fluctuation is due to unwanted fluctuations in the light source (Otsuka col. 4 ll. 58-65). Otsuka teaches a feedback control system to compensate for the unwanted fluctuations in order to achieve a more accurate measurement with an otherwise traditional interferometer device (Otsuka col. 2 ll. 29-32, Fig. 3, col. 2 ll. 61-64, and col. 5 ll. 43-60).

Claim 9 depends from Claim 8 and recites the addition of a frequency shifter for the phase modulated carrier signal. This frequency shifter together with the phase modulator is not taught or implied in Otsuka.

Claim 10 depends from Claim 8 and provides that the comparator comprises an intensity comparator. The present specification teaches that the target and local beams travel unequal path lengths in reaching the signal photodetector, and therefore the pure phase modulation gets converted into intensity modulation at frequency Ω. The electrical output of the signal photodetector is synchronously detected at frequency Ω (Specification page 3 ll. 2-5). Otsuka does not teach phase modulation, conversion into intensity modulation, or detecting of intensity. Applicant respectfully submits this intensity comparator is not taught or implied in Otsuka.

Claim 11 is a method drawn to the matter of Claims 7, 8 and 10. Claim 12 depends from Claim 11 and further provides a method drawn to the matter of Claim 9.

Claim 14 is a method that recites both phase modulating the carrier signal at a modulation frequency Ω and demodulating the output of a photodetector at the modulation frequency Ω to isolate a self-interference signal from a true signal. As discussed above, Otsuka does not teach or imply phase modulation of the carrier signal. Further, this isolation of the self-interference signal is neither taught nor implied by Otsuka.

Based on at least the discussion above, Applicant respectfully submits that the Otsuka reference does not teach the above described claimed elements or steps, and cannot anticipate the present invention as claimed. Applicant respectfully requests this rejection be withdrawn.

The Office Action rejected Claims 1-6 and 15-18 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claim 11 of U.S. Patent No. 6,646,723. Applicant respectfully traverses this rejection in its entirety. Applicant acknowledges that he is named as a co-inventor of the '723 patent.

Applicant respectfully submits that both the structure and function of the present invention as claimed are different from the apparatus taught by the '723 patent. As discussed above, the present invention is drawn to a method of <u>minimizing self-interference</u> (Specification page 2 ll. 16-20). The present invention, as defined in both Claim 1 and Claim 15, includes a signal mixer for mixing the phase-modulation frequency with the output of the signal photodetector to shift the target signal to the heterodyne frequency f and shift the self-interference signal into sidebands about the phase modulation frequency. Applicant respectfully submits that this element is neither taught nor implied by the '723 reference either in Claim 11 or

anywhere else in the '723 disclosure. The concept of self-interference is mentioned once in the '723 reference, but the relevant section actually teaches away from the solution of the present invention, saying:

> A metrology scheme using direct intensity modulation of the optical carrier signal would require detection and processing of high frequency signals (approximately 120 GHz). However, efficient photodetectors that can operate at these frequencies do not currently exist and therefore the detection of this modulation, if possible at all, would require high optical power. For many proposed applications of the sensor of the present invention, a constraint that the sensor operate with low received optical power precludes this possibility. Further, methods for dealing with high levels of *self-interference* have been developed for heterodyne interferometers, but presently there are no comparable methods that exist for direct modulation systems. ('723 reference col. 2 ll. 55-67, emphasis added)

Further, the present invention, as defined in both Claim 1 and Claim 15, includes a bandbass filter at the heterodyne frequency f to isolate the target signal and exclude the self-interference signal. Claim 15 further recites the first quarter-wave plate element and the second quarter-wave plate element for rotating the orientation of the reflected target beam $90^\circ + 90^\circ = 180^\circ$ prior to combining with the optical reference beam. Applicant respectfully submits that these elements are neither taught nor implied by the '723 reference.

The signal mixer element and the bandpass filter element enable the present invention to minimize self-interference and thus to perform distance measurement in a different way and with a different result than that disclosed by the '723 patent. Applicant respectfully submits that since the signal mixer element and the bandpass filter element as claimed in the present invention are neither taught nor implied in the cited reference, and the present invention performs distance measurement in a different way with a different result, and the cited reference does not render the present invention unpatentable under the judicially created doctrine of double patenting.

The Office Action suggests that "the present application disclose the same basic structure of the apparatus as disclosed in claim 11 of the patent, with a few minor, non-critical differences". Applicant respectfully traverses this assertion since signal mixer element, the bandpass filter element, the first quarter-wave plate element, and the second quarter-wave element as claimed enable the present invention to perform distance measurement in a different way, with a different result, than that which is disclosed in the '723 reference, as discussed above.

Applicant respectfully requests this rejection be withdrawn.

Regarding the *Response to Arguments* section, Applicant respectfully submits that the above arguments are fully responsive to the arguments against patentability as offered in the Office Action, and that the arguments are based on the claimed invention. As discussed above, Applicant respectfully submits that the Otsuka reference does not anticipate the present invention since Otsuka does not disclose the improvement of isolating the target signal and excluding the self-interference signal as claimed in the present invention.

CONCLUSION

It is believed that all claims are in condition for allowance, and an early notification of the same is requested.

If there are any questions with regard to prosecution of this case, the undersigned attorney can be contacted at the listed telephone number.

I hereby certify that this correspondence is being deposited with the U.S. Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on this 8 day of March, 2004.

by:

John H. Kusmiss
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Date of Signature: March 8, 2004

Sincerely yours,

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Introduction to AO Modulators.

Acousto-optic components are used in laser equipment for electronic control of the intensity and position of the laser beam. In this note, we will explain the theory and application of acousto-optic modulators. Acousto-optic interaction occurs in all optical medium when an acoustic wave and a laser beam are present in the medium. When an acoustic wave is launched into the optical medium, it generates a refractive index wave that behaves like a sinusoidal grating. An incident laser beam passing through this grating will diffract the laser beam into several orders. With appropriate design, the first order beam has the highest efficiency. Its angular position is linearly proportional to the acoustic frequency, so that the higher the frequency, the larger the diffracted angle.

This is the angle between the incident laser beam and the diffracted laser beam, with the acoustic wave direction propagating at the base of the triangle formed by the three vectors. A diagram of the angular relationship between the acoustic wave and the laser beams is shown in Figure 1. The intensity of light diffracted (deflected) is proportional to the acoustic power (Pac), the material figure of merit (M), geometric factors (L/H) and inversely proportional to the square of the wavelength.

With acousto-optics, both deflection as well as modulation of the amplitude of the laser beam are possible. Also, in the acousto-optic interaction, the laser beam frequency is shifted by an amount equal to the acoustic frequency.

This frequency can be used for heterodyne detection applications, where precise phase information is measured. For more information on the analysis and design of acousto-optics, refer to references #1, #2, and #3.

ACOUSTO-OPTIC MATERIAL SELECTION

A variety of different acousto-optic materials are used depending on the laser parameters such as laser wavelength (Optical transmission range), polarization, and power density. Table 1 is a summary of the most common materials used for the NEOS acousto-optic modulators. For the visible region and near infrared region the common modulators are made from dense flint glass, tellurium oxide, chalcogenide glass or fused quartz. At the infered region, germanium is the only commercially available modulator material with a relatively high figure of merit. Lithium niobate, and gallium phosphide are used for high frequency signal processing devices.

ACOUSTO-OPTIC MODULATOR/DRIVER CONSTRUCTION

Once the acousto-optic material is selected, it is optically polished, and a lithium niobate transducer is metal vacuum bonded to the modulator medium. Metal bonding provides a much better acoustic coupling than epoxy bonding. NEOS used only high quality metal bonds. Then the transducer is lapped to the fundamental resonant frequency such as 80MHz. The RF drive usually consists of an RF oscillator, an amplitude modulator with an interface which accepts input modulation, and an RF amplifier which drives the AO modulator. The specifications in the brochures describe the performance of the modulator/driver systems in detail.

DIGITAL MODULATION AND LASER BEAM SHUTTERING

The acousto-optic modulator is used to shutter the laser beam on and off by an external digital TTL signal. The TTL signal allows for easy interface to a computer. To support the on-off signal, the rise time of the modulator system has to follow the digital waveform transition. The limit of the acousto-optic modulator rise and fall time is the transit time of the acoustic wave propagation across the optical beam. the rise time is given by:

$tr = DIA/(1.5\ Va)$

A typical rise time for a 1 mm diameter laser beam is around 150 nanoseconds. To achieve faster rise times, it will be necessary to focus the laser beam and decrease the acoustic transit time. A schematic of the focused modulator setup is shown in Figure 1. Since the incident beam is a convergent instead of a collimated beam, the diffraction efficiency decreases as the ratio of the optical beam convergence and the acoustic beam convergence angle increases. For those interested in the design procedure for a wide bandwidth acousto-optic modulator, refer to reference 1.

ANALOG MODULATION

The acousto-optic modulator has a nonlinear transfer function, and as a result care must be exercised in using it as an analog modulation system. For simple grey level control, the best approach is to characterize the transfer function and apply the appropriate voltage levels into the 50 ohm impedance input drive port. For sinusoidal modulation, a bias is required to move the operating point to the linear region of the transfer function and focussing may be necessary to ensure that the rise time is adequate. The modulation transfer function model is given by Figure 3.

$MTF=\exp(-(fm/1.2fo)2)$; $fo=.35/tr$

where fm is the modulating frequency

The modulation contrast ration can also be obtained from experimental measurements:

$MT=(Imax-Imin)/(Imax+Imin)$

where Imax = max laser intensity measured Imin = min laser intensity measured

The contrast ratio is defined as:

$CR=Imax/Imin$, for the First Order Beam

In the DC case, the Imin consists of contributions of the scattered light and of light modulation from leakage RF power driving the modulator. For optimum contrast ratio, Imax must be optimized, and also by changing the operating frequency to an idle frequency, this leakage light can be blocked. An optimized DC contrast ratio is between 500 to 1000.

In the dynamic contract ratio, Imin increases as the modulation frequency increases and the modulator frequency response degrades in performance.

ANTI-REFLECTION OPTICAL COATING

NEOS uses multilayer dielectric broadband or "V" AR coatings for the AO modulators. Typical losses are from a few percent for external cavity devices to 0.2 percent for intracavity devices. Typical AR coating transmission curves are available on request.

APPLICATIONS

Acousto-optic modulators can perform other tasks in modulating the laser beam in addition to digital and analog modulation. For example, a closed loop laser control system can be built using the AO modulator to sample and regulate the laser beam output power. There are applications that make use of the frequency shift in the light beam for hetrodyning to measure distance and velocity accurately.

Internal laser cavity modulators generate high power laser pulses that have many useful applications. CW pumped Nd:YAG lasers produce > 10kw power pulses with pulse widths of 40-200 nanoseconds wide. The rep rate is up to 50 KHz. Cavity dumping of Ar+ and Nd:YAG lasers has a rep rate of up to 1 MHz. The peak power for the argon laser is around 100 watts and a pulse width of 15 nanoseconds. Mode locking of the laser produces very narrow pulses. The narrowest pulse width is around 40 picoseconds for the Nd:YAG laser at a constant rep rate of 80 MHz. NEOS personnel can assist you in answering technical questions in regard to acousto-optic modulator systems.

GLOSSARY

M2 Acoustic Figure of Merit
Pac Acoustic Power in Watts
tr Modulated Laser Beam Rise Time
DIA Laser Beam Diameter
MTF Modulation Transfer Function
fm Modulation Frequency
fo Characteristic Frequency
Imax Maximum Intensity
Imin Minimum Intensity
CR Contrast Ratio
"V" Coat Narrow Band AR Coating
b Bragg Angle in radians
2 b = Deflection Angle in radians
Optical Wavelength in free space in meters
fa Acoustic Frequency in MHz
Va Acoustic Velocity in meters/sec.
Diffraction Efficiency of Modulator
L Interaction Length
H Transducer Height

REFERENCES

1. J.R. Boyde, E.H. Young, and S.K. Yao, "Design Procedure for Wide Bandwidth Acousto-Optic Modulators", Optical Engr. pp 452-454, Sept. 1977

2. I.C. Chang, "Acousto-Optic Devices and Applications", IEEE Trans. on Sonics and Ultrasonics, pp 1-22, Jan. 1976

3. E.I. Gordon, "A Review of Acousto-Optical Deflection and Modulation Devices", Proc. IEEE, pp 1391-1401, Oct. 1966

Return to NEOS Catalog

Return to NEOS Homepage